

Planar Doppler Velocimetry: Three-Component Velocity Measurements in a Full-Scale Rotor Flow Field

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Planar Doppler velocimetry (PDV) is an optical, laser-based flow-field measurement technique that is being developed for the large wind tunnels at Ames Research Center. The PDV technique measures the Doppler shift of light that is scattered from aerosol particles that are added to the flow and illuminated by a pulsed laser sheet. Images of the planar measurement region are acquired with scientific-grade digital cameras and then processed to yield instantaneous, three-dimensional (3-D) velocity maps, which are limited in size only by the field of view of the cameras and any requirement to meet a particular spatial resolution.

The PDV concept is based on the sensitive frequency discrimination that occurs when the scattered laser light is viewed through an optical filter cell containing iodine vapor. Particles moving with the flow pass through the laser sheet and scatter light that is shifted in frequency according to the Doppler effect. Some of this light is collected to form an image that records intensity variations not caused by the Doppler effect. These variations are caused primarily by nonuniform aerosol distribution and nonuniform illumination. Simultaneously, some of the light is collected and imaged through the optical filter cell containing the iodine vapor. This cell acts as a sharp spectral filter at the laser frequency. Because the Doppler-shifted laser light has a narrower bandwidth than the spectral range of the iodine absorption feature edge, Doppler shifts of the collected light are converted to variations in recorded image intensity as the frequency moves on the filter edge. In its full implementation, pairs of filtered and unfiltered images are simultaneously acquired during each laser pulse by using three camera systems that view the laser sheet from three different locations. The filtered images are normalized by the unfiltered images to eliminate the variations in intensity that are not related to the Doppler effect. These normalized images are processed and become quantitative velocity map images of three separate, instantaneous

velocity-field components. An algebraic transformation yields the complete 3-D orthogonal velocity vector field.

At Ames Research Center, the PDV technique, along with its related optical hardware and data analysis software, has been shown in the laboratory to be capable of resolving instantaneous velocities as low as 2 meters per second from a single pulse and to be applicable at ranges exceeding 40 meters. These capabilities, in addition to the minimal requirements of PDV on the optical and density properties of the aerosols that must be added to the flow, make it particularly attractive as a means of measuring 3-D velocity vector fields in time-dependent flows in large-scale facilities where full-scale rotor tests are conducted and velocity vector-field measurements between turning rotor blades are of interest.

The PDV system was first used in the wind tunnel environment during the XV-15 rotor test in the Ames 80- by 120-Foot Wind Tunnel. That test was conducted to determine fundamental differences in blade vortex interaction (BVI) noise for this tilt rotor in approach flight configuration. The first figure shows a diagram of the test section and measurement geometry. The three camera locations are shown along with the respective measured velocity vector directions. The camera field of view is indicated by the square region in the laser sheet. Measurements were acquired at various stations behind the rotor blade using a variable time delay to synchronize the laser pulses and camera shutters with the rotor azimuth. The second figure shows the computed, single-pulse 3-D orthogonal velocity vector field. The view is normal to the measurement plane; in-plane velocities are shown as vectors, and out-of-plane velocities are shown as color contours. Also shown is the position of the rotor blade, which is 22.6 degrees upstream of the measurement plane in this case. Free-stream velocity, rotor-shaft angle, and advance ratio simulate the tilt-rotor approach configuration.

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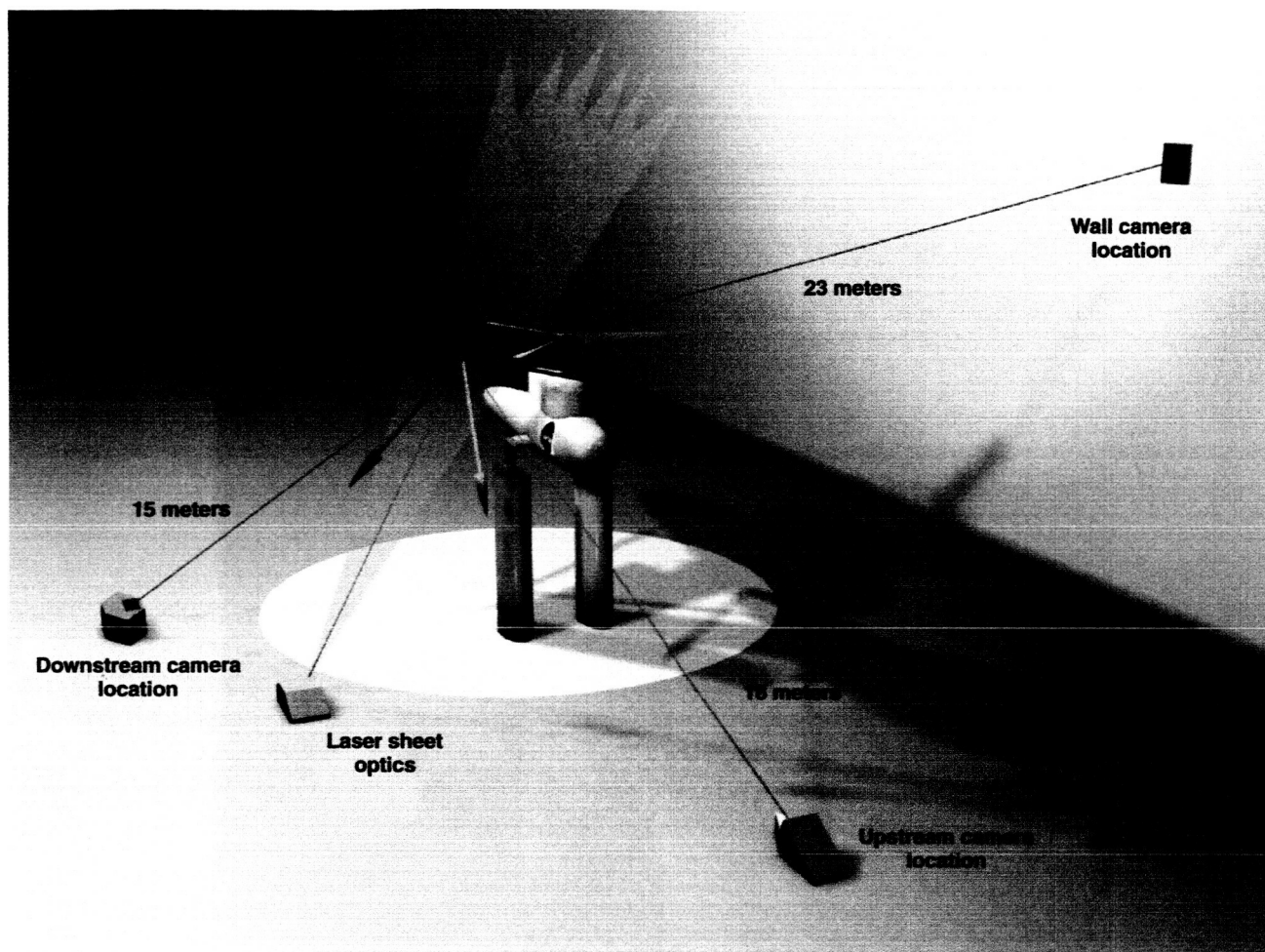


Fig. 1. XV-15 rotor and PDV system configuration in the Ames 80- by 120-Foot Wind Tunnel; vectors indicate the respective measured velocity component directions.